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Digital Manufacturing – a Strategy for Engineering Collaboration

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Abstract

How to achieve engineering collaboration among diverse engineering activities is one of the key topics in manufacturing fields nowadays. The infrastructure for collaborative engineering is essential, and it can be realized by information technologies and intelligent engineering applications in digital environments. Digital Manufacturing is a technology to facilitate effective product developments and agile productions by computer models representing the physical and logical schema and the behavior of real manufacturing systems including products, processes and factories. A digital factory as a well-designed and integrated digital environment is incorporated in it. In this paper, digital manufacturing is recommended as a good strategy for collaborative engineering, especially in product developments and productions. By business process analysis and some case studies, we suggested sophisticated digital models are very useful to concurrent and collaborative engineering. It is expected that digital manufacturing is a very good strategy for achieving dramatic time and cost savings in many engineering activities of many manufacturing industries, including machinery, automotive and shipbuilding.

Keywords: digital, manufacturing, engineering, collaboration

1 Introduction

Nowadays, one of the major issues in manufacturing fields is how to achieve engineering collaboration among diverse engineering and production activities. Engineering collaboration means a team-based exchange of useful lifecycle engineering information and resources to create a shared understanding to resolve a common need within the concurrent engineering environment (Mills 1998). This engineering collaboration has to be performed interactively by developers, manufacturers, suppliers and customers through an entire product life cycle. For implementation, the infrastructure such as a new business process, a database, supporting applications, and etc. is very important, and the common united model which covers all engineering functions, information flows and precise behaviors of products, processes, and resources in manufacturing systems is needed (Iwata et al 1995, Lee et al 1997, Noh 1999).

Digital manufacturing is a technology facilitating effective development and agile production via computer models representing physical and logical schema and the behavior of the real manufacturing systems (Onosato et al 1993, Kimura 1993). It is not only a well-designed and integrated model and environment, but also a good paradigm to drive a

collaborative and concurrent engineering through an entire product life cycle. Because a digital manufacturing system is consist of all products, processes and resources of manufacturing system, examining many engineering paradigms, decisions, plans and analysis of manufacturing activities, such as design, manufacturing preparation, production planning and shop floor control are possible(Iwata et al 1997, Lee et al 1997). Using this technology, many activities in manufacturing can be integrated and realized into one system, and thus, manufacturing cost and time-to-market can be reduced and productivity can be improved dramatically. According to current reports on digital manufacturing, time and cost for making jigs and fixtures were reduced more than 75% in aerospace industries, errors in design of molds and dies decreased about 50% in machining shops, and total development time of production lines was saved more than 20% in automotive industries. For shipbuilding, digital manufacturing is inevitable, as major customers simply mandated diverse manufacturing simulations as a precondition for the contract (Brown Associates 1999). Figure 1 shows concepts and the structure of digital manufacturing.

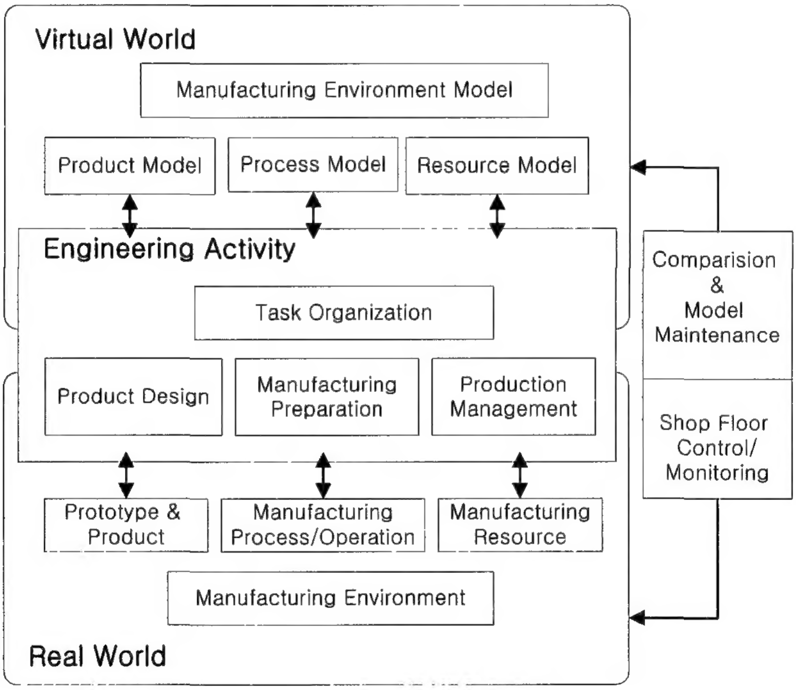

Figure 1: The concept and structure of a digital manufacturing

In this paper, digital manufacturing is recommended as a good strategy for collaborative engineering especially in product developments and production. By business process analysis and some case studies for a design, manufacturing preparations and a process planning, we suggested sophisticated digital models in digital manufacturing are very useful to concurrent and collaborative engineering of many manufacturing industries, including machinery, automotive and shipbuilding.

2 Business process analysis and effects of digital manufacturing

The main objectives of a business process analysis and strategic planning in this paper are making suitable business workflow and blueprint of enterprise-wide infrastructure for

collaborative engineering. General methodologies, such as IDEF, UML for systematic functional analysis and workflow modeling can be used.

Figure 2 shows an example of the business processes for product development and production in automotive companies. Diverse engineering activities such as a design, planning, testing and analysis are performed concurrently, and designs, control programs, prototypes, products must be performed in concurrent and collaborative manners. Generally, the digital manufacturing technology can be realized on effective management and utilization of information about product, process, resource and their relations. By this technology, new ideas and its feasibilities can be evaluated concurrently in the PLANNING stage, visualizations, digital testing and analysis of new products can be done in the PRODCUT DESIGN AND DEVELOPMENT and the PRODUCT AND PROCESS EVALUATION. Evaluation and optimization of layouts, processes, operations and production equipments in the PROCESS DESIGN AND DEVELOPMENT and the PRODUCT AND PROCESS EVALUATION can be done. Finally, improve productivity and save cost are possible by collaborative and concurrent engineering in decision-making and optimization procedures. Areas and effects of digital manufacturing in the manner of engineering collaboration are listed below,

- Environments for digital engineering
  - Interfaces with CAD, integrated environments for modeling and evaluation of buildings, equipments, machines, jigs and fixtures, etc.
  - Analysis and evaluation of products and their parts by CAD models and DMU.
- Design and operation of a factory
  - Modeling and information management of buildings, equipments and machines.
  - Process planning and scheduling, optimization by line and factory simulations.
  - Layout designs and machine maintenance for diverse factories.
  - Multi-media training manuals for human operators.
- Validation and evaluation of products and processes
  - Coding, evaluation and optimization of NC programs for machining process.
  - Design and evaluation of jigs and fixtures.
  - Robot simulation and off-line programming.
  - Interference check and optimization of assembly operation by digital assembly.
  - Ergonomics and safety analysis for many manual operations.
- Line Simulations
  - Material flow, bottle-neck and alternative analysis by line simulations.
- Inspection and quality managements
  - Off-line programming of computer controlled measuring machines.
  - Quality estimation and control.
- Visualization of product, process and resource
  - Easy understand all information about the product, process and resource.
  - Multi-media operation manuals.

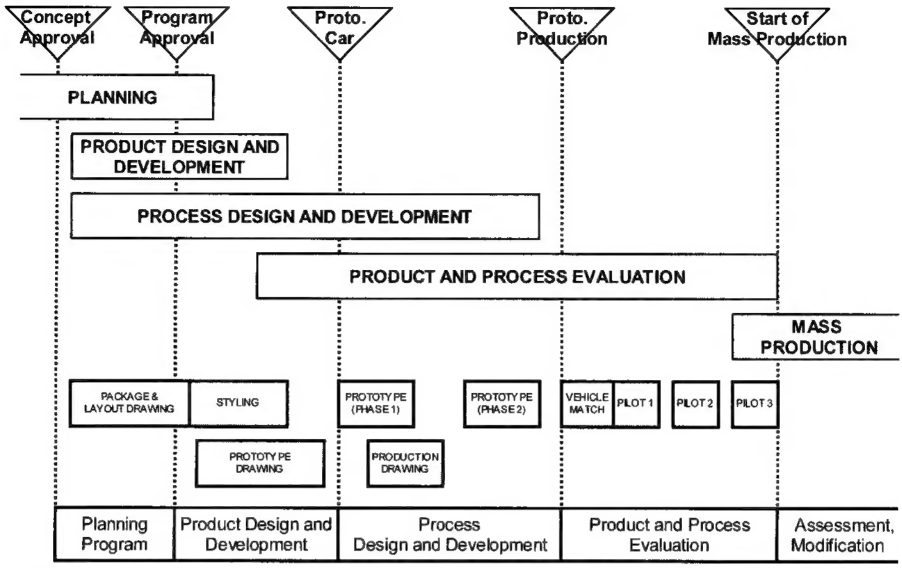

Figure 2: Business process for product developments and productions of automotive companies

Table 1: Recommended engineering activities for press shops

Area	Effect	Data
Manufacturability of panels and dies	Virtual engineering	P
Evaluation of verification model	Virtual engineering	P
Evaluation of prototype drawing	Virtual engineering	P
Jig/fixture design and production	Visualization and verification of PR	P/PR/R
Evaluation of manufacturing process	Verification of PR	P/R
Productivity of transfer line	Verification of PR	P/R
Evaluation of patterns	Verification of PR	P
Training operators	Visualization of P/PR/R	P/PR/R
Planning and preparation for inspection	Verification PR	P/R
Evaluation racks	Verification of PR	P/PR/R

* P: product, PR: process, R: resource

Table 2: Recommended engineering activities for body shops

Area	Effect	Data
Welding operation	Verification of PR	P/R
Robot P/G	Verification of PR	P/R
Evaluation operations	Verification of PR	P/R
Evaluation modules	Virtual engineering	P/R
Evaluation welding sequences	Virtual engineering	P/PR/R
Evaluation material flows	Factory simulation	P/PR/R
Evaluation loading/uploading parts	Verification of PR	P/R
Evaluation equipments	Design and operation of plant	P/PR/R
Line tryout	Factory simulation	P/R
Vehicle match	Factory simulation	P/PR/R
Evaluation cycle time	Factory simulation	P/PR/R
Training operators	Visualization of P/PR/R	P/PR/R

* P: product, PR: process, R: resource

Workflow modeling and analysis of engineering activities for manufacturing preparation and production were carried out in this paper. As-is and to-be model are formulated using IDEF1 and IDEF3, information model of to-be workflow is made by IDEF1X methodology, and workflow simulations are performed to evaluate benefits and effects of new business workflow (Jablonski et al 1996). Each engineering activities decomposed more and more in detail, and we made almost 300 activities and their relations, resources, methods. Based on workflow analysis, engineering activities which are suitable for adoption of digital manufacturing are found. Detail steering plans, comprehensive design of database, and preparations for data are performed. We concluded more than 75 activities are suitable for digital manufacturing. Table 1, Table 2, Table 3 and Table 4 show areas, effects and needed data of each engineering activity which are recommended for digital manufacturing.

Table 3: Recommended engineering activities for paint shops

Area	Effect	Data
Evaluation drawings	Design and operation of plant	P/PR/R
Evaluation equipments for material handling	Virtual engineering, verification of PR	P/R
Evaluation interferences	Design and operation of plant	P/R
Evaluation quality of painting	Inspection/quality control	P/PR/R
Design and evaluation of hanger/skid	Virtual engineering, verification of PR	P/PR/R
Evaluation jigs/fixtures	Virtual engineering, verification of PR	P/PR/R
Evaluation layout of operators	Verification of PR	P/R
Evaluation equipments	Design and operation of plant	P/R
Training operators	Visualization of P/PR/R	P/PR/R

* P: product, PR: process, R: resource

Table 4: Recommended engineering activities for general assembly shops

Area	Effect	Data
Package concepts	Virtual engineering	P
Evaluation engine room package	Virtual engineering, verification of PR	P/R
Evaluation concepts of modules	Virtual engineering, verification of PR	P
Evaluation drawings and proto. cars	Virtual engineering, design and operation of plant	P/R
Evaluation equipments for material handling	Virtual engineering, design and operation of plant	P/R
Evaluation exterior/interior	Virtual engineering	P
Evaluation process and equipments	Design and operation of plant, verification of PR	P/PR/R
Evaluation tolerance for assembly	Virtual engineering	P
Design and evaluation of special tools	Verification of PR	P/R
Production Drawings	Verification of PR	P/R
Evaluation layout and material flow	Factory simulation, visualization of P/PR/R	P/PR/R
Evaluation part lists for operations	Visualization of P/PR/R	P/PR/R

* P: product, PR: process, R: resource

A digital factory is integrated infra-structure for digital manufacturing including CAD and simulation models of machines, equipments, work cells, lines and plant. Figure 3 shows a general procedure to construct a digital factory. It takes much time, cost and resources, so effective action plans and objectives are essential. To construct a digital factory, 3-dimensional CAD and simulation model must be implemented. Both modeling works need considerable time, cost and efforts. So, technologies developments for an effective measuring and geometric modeling, a knowledge based CAD and simulation, and reuse models are essential. In addition to these technologies, systematic planning, determinations of detailed scopes and model maintenance are also very important.

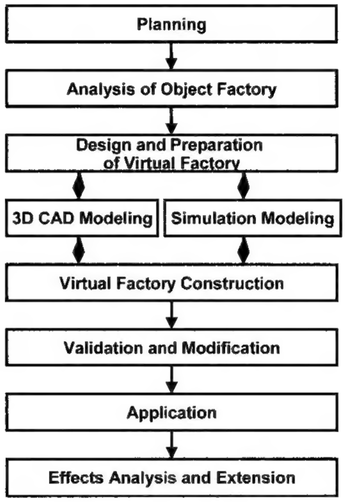

Figure 3: Procedures to construct a digital factory

3 Case studies for collaborative engineering via digital manufacturing

This paper will give explanation about case studies, the collaborative design and manufacturing of a press-die, the collaborative and continuous verification of products, processes and resources in automotive body assembly shops, and the collaborative process planning for an automotive general assembly. These will be great examples to show practical steering strategies, methods and effects of digital manufacturing for engineering collaboration of many manufacturing industries.

3.1 Collaborative design and manufacturing of a press-die

A general press-die consists of blank holder, upper die and lower die. A panel is settled with the blank holder and the upper/lower die. The upper die and lower die are designed on the basis of holder design and they have cast surface inside. In general, the press process has 4 steps, such as drawing, trimming, flanging/piercing and CAM. There are 9 major engineering activities for designing and manufacturing dies, and business and information flow among them is shown in Figure 4(Kong at el 2002). The "Process Planning" makes process plan including 3 dimensional layouts and their processes from part designs, and the "Digital Manufacturing(stamping analysis)" evaluates the results of the "Die Design" activity. Based on process plan and part designs, the "Die Design" makes 3-D models for punch, blank holder and lower dies in cooperation with digital manufacturing activities including stamping analysis and assembly simulation. After NC data generated by the

"Date Generation", NC data, tools and machining conditions are verified by the "Digital Manufacturing(NC machining)". In this activity, machining condition optimization, collision check, evaluation of press conditions are performed by digital manufacturing.

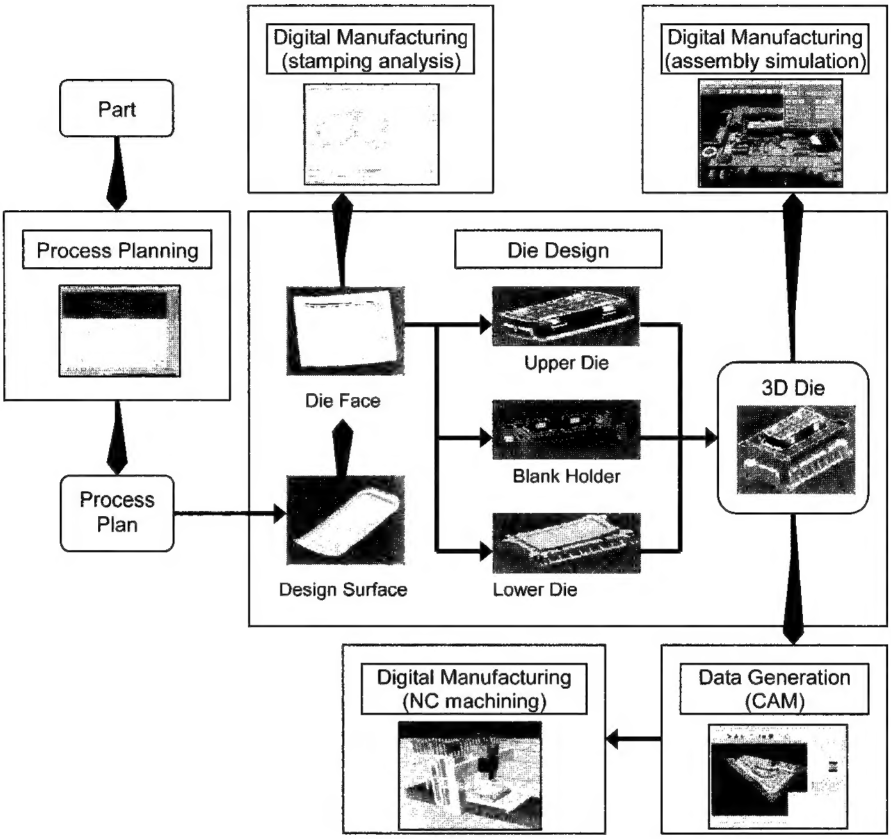

Figure 4: Collaborative die design using digital manufacturing

Based on the experiences of this case study, three major effects can be expected for the collaborative engineering, shorten die manufacturing time, improve machining productivity and design quality.

- Die manufacturing time
  The die manufacturing time means total time through design, pattern production, machining and tryout. This period can be shortened about 10%(from 15 months to 13.5 months). This is caused by reductions of design and engineering changes followed after realizations of concurrent and collaborative engineering.
- Machining productivity
  By optimization and pre-evaluation of many parameters, tools, jig and fixtures using digital manufacturing, machining productivity can be improved dramatically, more than 40%.
- Design quality
  The quality of die design can be enhanced about 20%. Using digital manufacturing, dynamic simulation and computer analysis, design engineers can evaluate their design concurrently and improve new design in successful cooperation with other engineers.

3.2 Collaborative and continuous verification of products, processes and resources in automotive body assembly shops

In the automotive body shop, a BIW(Body In White) is assembled by welding operations of panels which are produced in the press shop. Almost all welding operations are performed automatically by computer controlled robots. Engineering activities for collaborative engineering via digital manufacturing are as follows:

- Evaluation of existing equipments when design changes or new car production.
- Evaluation of new equipments and new processes, especially interference checks among jigs, fixture, products, facilities and robots.
- Evaluation of material handling equipments, operation strategies and areas.
- Off-line programming of robots for welding and material handling.
- Off-line programming of computer controlled measuring machines for quality controls.
- Visualization of cells, lines and factory for easy understanding of operators.
- Integrated management of information about factory and production, and knowledge managements
- Effective control and monitoring systems by PLCs, H/Ws and database interface.

Figure 5 and figure 6 show digital models for verification of manufacturing process and resources by 3-D CAD and simulation.

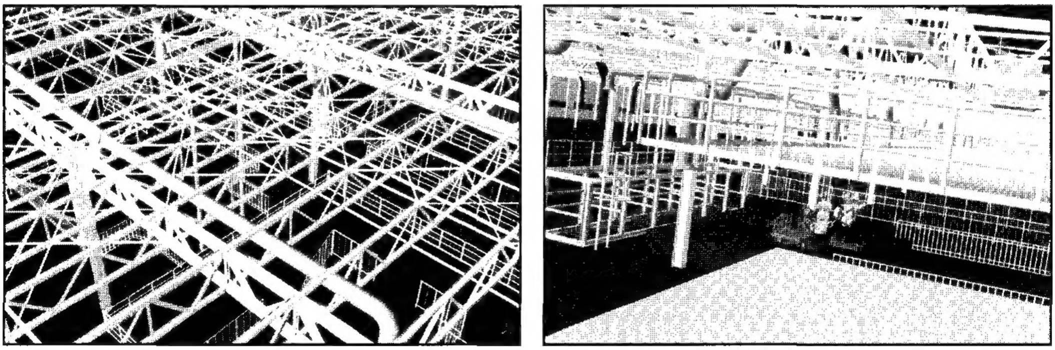

Figure 5: digital models for verification of manufacturing resources

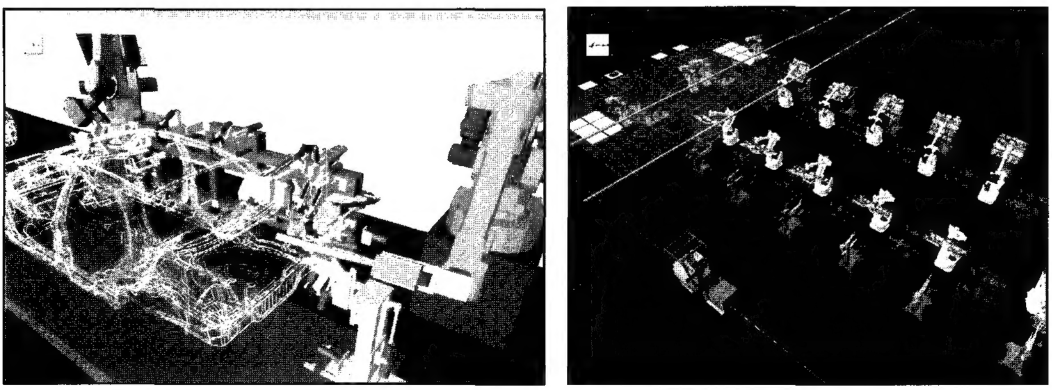

Figure 6: digital models for verification of manufacturing processes

Results and effects of collaborative and continuous engineering in the automotive body shop are like following:

- Verifications using 3D CAD models
- By evaluations, the accuracy of the CAD models in this paper are 5~10mm for models. These 3D models can be used for the interference check and the process evaluation.
- Validity of simulation models
- The operating logics and cycle time in the digital factory are almost same with the real factory, but storage areas and results of material handling are little different with those real situations. This is mainly caused by differences between real situations and the simulation in human factors of operators.
- Work cell and off-line programming
- Reliable simulations and the off-line programming of every work cells consist of robots can be possible. In this case, we can save 0.4 million USD and 60% time for robot code generations and preparations of each lines (Jung 2000)
- Visualization and collaboration
- Using 3-D CAD models and realistic simulations, easy understanding and collaborative engineering of products, processes and resources are possible.

3.3 Collaborative process planning for automotive general assemblies

Generally, an automotive general assembly shop has about 10 sub-lines, more than 300 workstations, almost 400 workers and at least 2,000 parts to be assembled per each car. The cycle time of each assembly operation is 36~60 seconds. The process planning for the general assembly line is directly connected with overall production planning and control system, and is performed by many process planners simultaneously. Because of the complicated business workflow and complex engineering problems in each process planning activity, the manufacturing preparation for the general assembly is a major obstacle to achieving rapid development of a new car. The assembly process in the automotive general assembly system consists of work elements, unit works and assembly processes. A work element is the minimum unit of an assembly operation and a unit work is a set of work elements. The general process planning steps are 1) determining work elements; 2) assigning work elements to a specific unit work; 3) deploying unit works into workstations of assembly lines; 4) checking the balance of the workload and prerequisites; and 5) modifying and rearranging unbalanced processes.

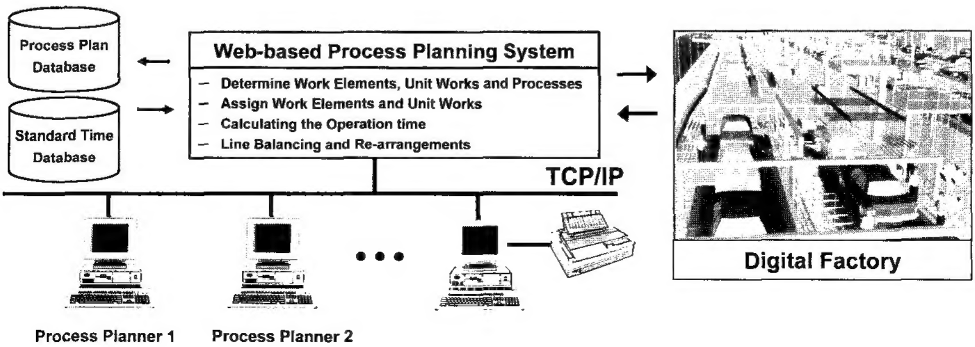

Figure 7: Collaborative process planning system

Figure 7 shows the structure of the developed collaborative process planning system. Process planners in separated environments can connect to this system through the Internet, make process plans, share related information and evaluate their results by digital manufacturing on-line.

This system was used in an automobile manufacturer, resulting in the successful completion of more than twenty general assembly process plans for four assembly shops. Using these applications, both process time and delay time were dramatically decreased. The total process time of the collaborative process planning is 16 days shorter than that of the existing business workflow (40% saving). The total delay time is also 8.5 days shorter than that of the existing workflow (70% saving). The savings in the total process time is mainly due to the reduction of the number of activities and the total delay time, which is caused by having to wait until another activity is completed. The existing workflow has a longer delay time than the collaborative process planning, because in the existing workflow, the process planner must collect other process planners' outputs in every activity. In the collaborative process planning, information collection is not required, since all the results are managed in a single buffer, which is the information-sharing and collaborative-process planning system. Information sharing and collaborative process planning dramatically reduced the engineering hours for process planning and improved the reliability and quality of resulting process plans.

4 Conclusions

In this paper, digital manufacturing is recommended as a good strategy for collaborative engineering, especially in product developments and productions. By digital manufacturing, the infrastructure for collaborative engineering, such as business workflows, a database, digital models, applications and etc. can be made and presented. This paper shows some case studies for collaborative engineering via digital manufacturing, and these will be good examples to show practical steering strategies, methods and effects of digital manufacturing for engineering collaboration. It is expected that digital manufacturing is a very good strategy for dramatic time and cost savings by achieving engineering collaboration in many engineering activities of many manufacturing industries, including machinery, automotive and shipbuilding.

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